Easily Quantify HVAC System Efficiency Loss Caused by Poor Installation

By Rob Falke & Ben Lipscomb, National Comfort Institute

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2018 AHR EXPO CHICAGO JAN 22-24

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About National Balancing Council & National Comfort Institute

At National Balancing Council (NBC), we have long known that true system performance and efficiency goes beyond traditional testing and balancing. NBC trained and certified professionals specialize in comprehensive HVACR system diagnostics. Technicians have the expertise to measure and verify *actual* system operating performance.

National Comfort Institute, Inc. (NCI) is the world leader in HVAC System Performance training and Air Balancing. We created the industry's best practices, processes, and forms and have been teaching them for decades. What makes NCI's approach different? We show you how to thoroughly test and diagnose the system using practical, easy-to-follow methods so you'll know exactly what to do to provide your customers with optimum comfort and energy efficiency. During the past two decades, NCI has trained and certified more than 25,000 HVAC industry professionals.

If You Don't Measure, You're Just Guessing™

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The parent company to NBC, NCI has offices and staff in 10 states across the USA. NBC is the *only* large commercial certification that also includes training as part of the certification process. NCI is active in HVAC utility energy savings programs as well. We hope that you enjoy this presentation, and if you want to learn more:

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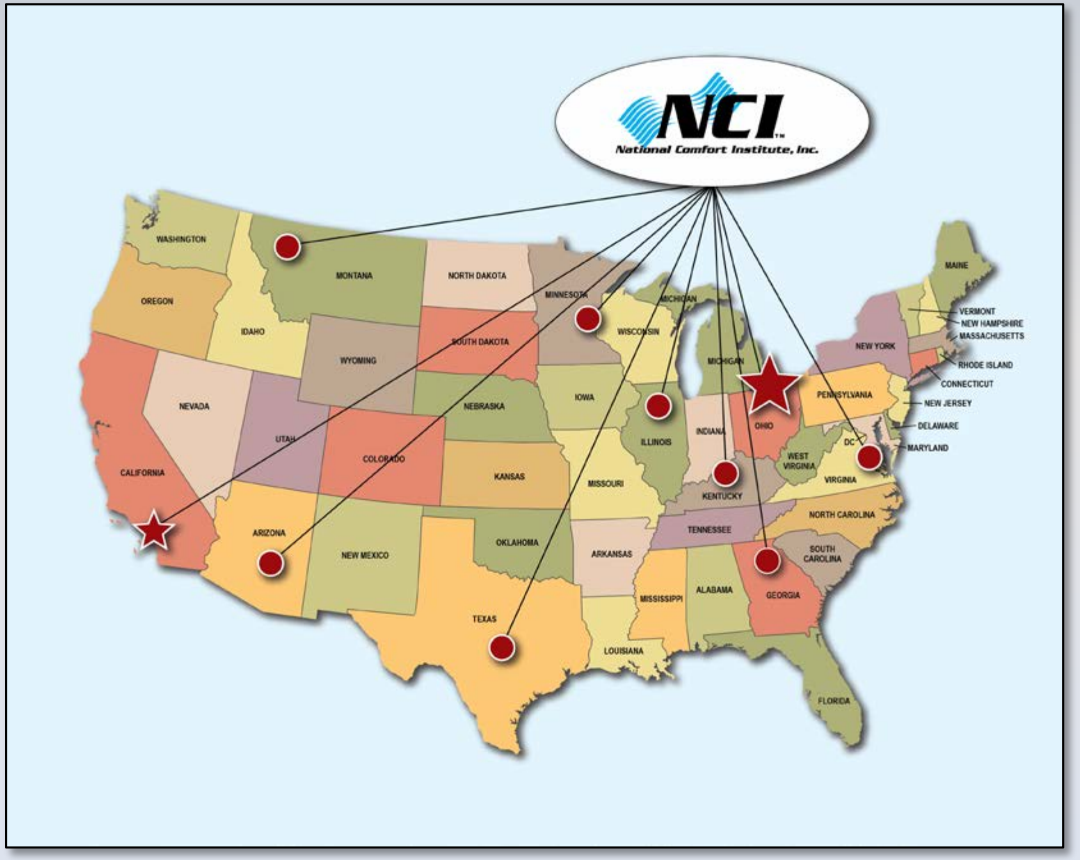

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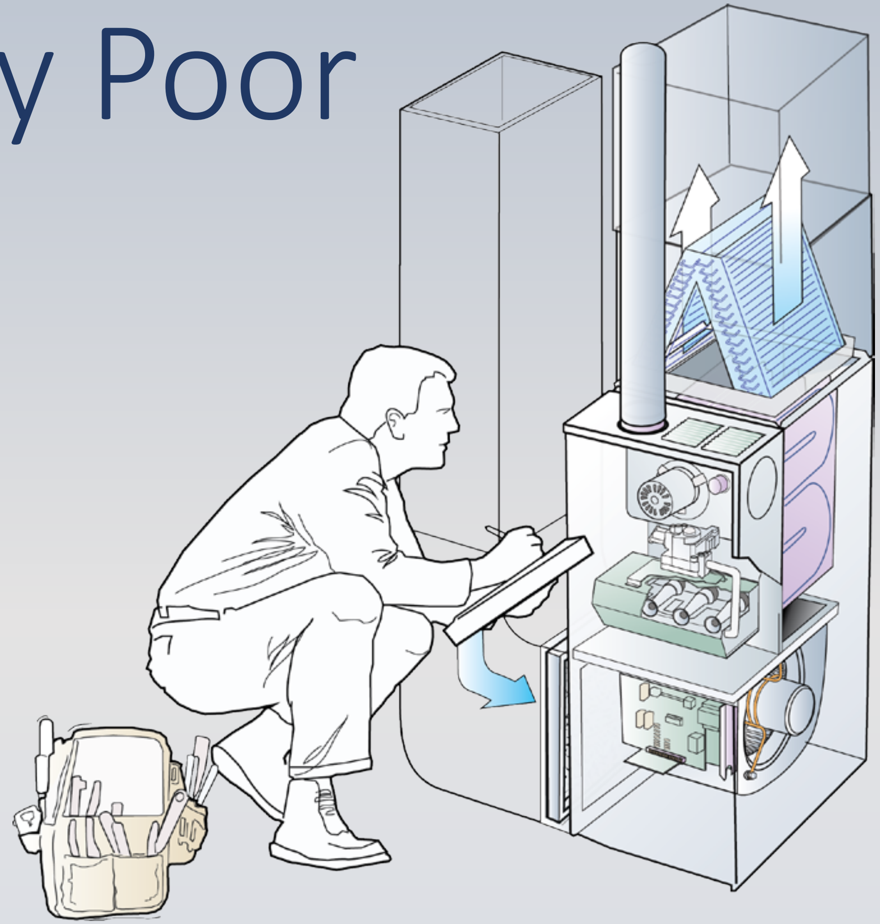

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If You Don't Measure, You're Just Guessing! ™

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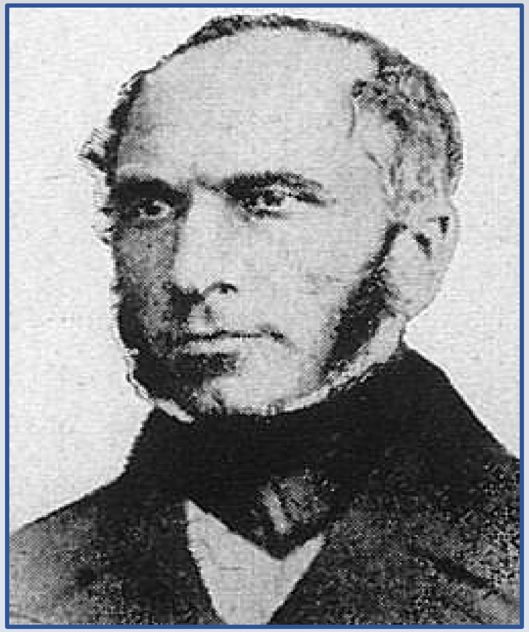
Field Performance Testing History

Henri Pitot – Invented the Pitot tube in 1732 and laid the foundation for air and fluid measurement

Henry Darcey – Test methods and use of Pitot Tube was further developed in the mid 1850's

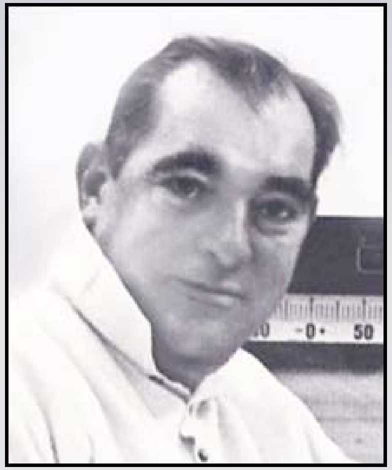


They formed the groundwork of performance testing today

Field Performance Testing - 1960’s and 70’s

Architects and Engineers became aware design intent was not materializing once systems were installed.

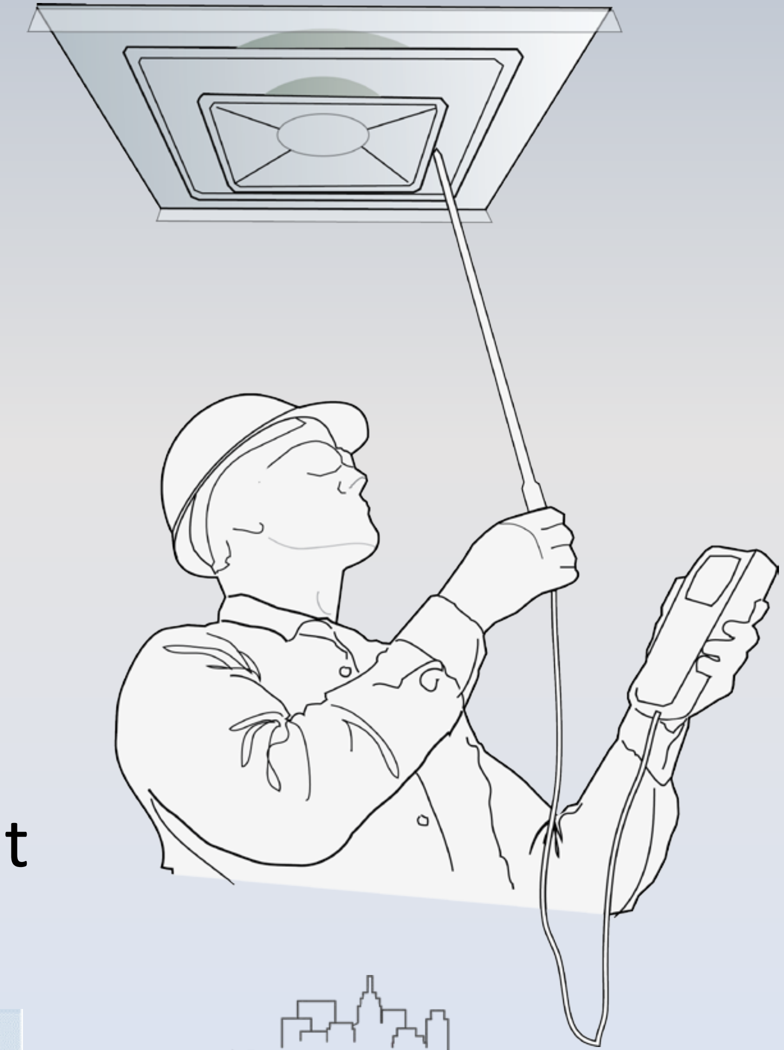
H. Taylor Kahoe – Founded Associated Air Balance Council in 1965



US Oil Embargo in 1973 – Efficiency took on the spirit of panic…we haven’t been the same since.

Field Performance Testing - 1980's

- Government and utilities jumped into the HVAC efficiency arena.
- Began with contractors, quite unsuccessful.
- Handed off to equipment manufacturers and utilities, who focused primarily on equipment efficiency.
- Both partnered with the building scientists to develop a method to indicate energy savings –tight ducts.



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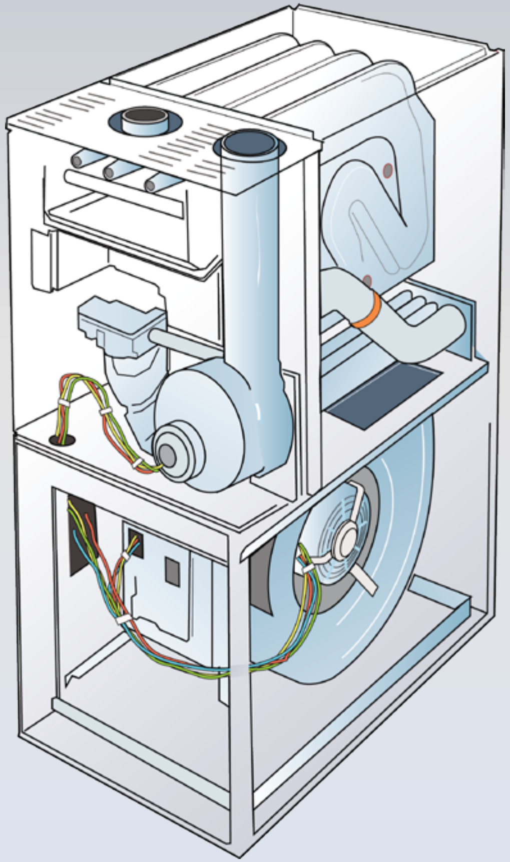
Field Performance Testing - 1990’s



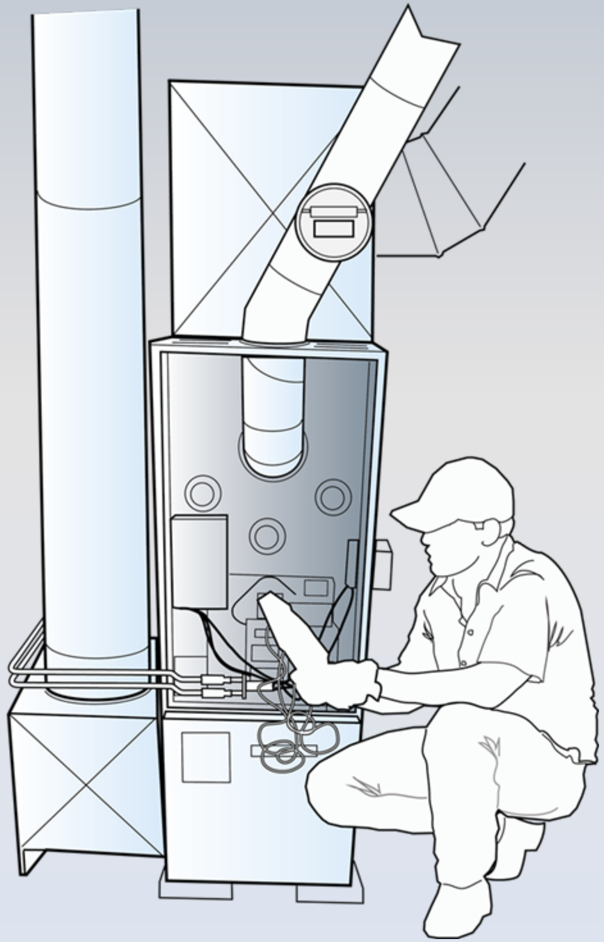
Equipment efficiency increased, but system efficiency remained the same – The Yellow Sticker was launched.

Duct Sealing was the rage – increased system static pressure and often decreased efficiency.

Software was created to “Deem” or generalize typical energy savings as an average kWh per ton

Airflow and testing was being adapted by the HVAC industry. Consistent with the testing they used daily

Field Performance Testing – 2000's



Outsiders are called in – The business of Energy Rating was created to do scientific testing to estimate HVAC system efficiency.

To the HVAC industry, it was like calling in a plumber to verify the work of a gastro-intestinal surgeon.

Meanwhile, the HVAC industry began to voluntarily embrace measurement of HVAC system performance

Field Performance Testing – 2010’s

Just as some had figured it out in the 1960’s, the HVAC industry players have rediscovered that design system efficiency did not produce installed efficiency.

Consumers, contractors, government and utilities soon began to embrace field performance testing.

Data began rolling in and a new source of energy savings was uncovered.

Legislation is being passed, requiring a new level of verification of savings matching this test method.

Thousands of field tests document this scoring method.

Looking Ahead to the Future…

An industry committee has written a standard to score the performance of HVAC systems.

Occasionally committee members mumble:

“The HVAC systems on the Starship Enterprise will be commissioned using this scoring method.”

We shall see…

How This Test Method Evolved

1980's Discovered balancing alone did not assure performance or efficiency

1990's Realized we had all the data to calculate system Btu - then we roamed around in a state of confusion for a year.

2000's Developed it by teaching it to others and supporting them in the field, constantly improving it over 20 years.

2010's Vetted this test method across the industry

Today we're working to give it away to the industry, seeking to turning it into a standard.

Overview - How to Measure System Efficiency Loss

1. Measure the airflow entering the occupied space.
2. Measure the average supply and return grille temperatures.
3. Calculate the system Btu entering the occupied space.
4. Calculate the system score by dividing the Btu entering occupied space by the rated equipment Btu.

53,000 Btu/hr Entering the building/100,000 equipment rated Btu/hr rated = 53%

100% - 53% = 47% Installation Efficiency Loss

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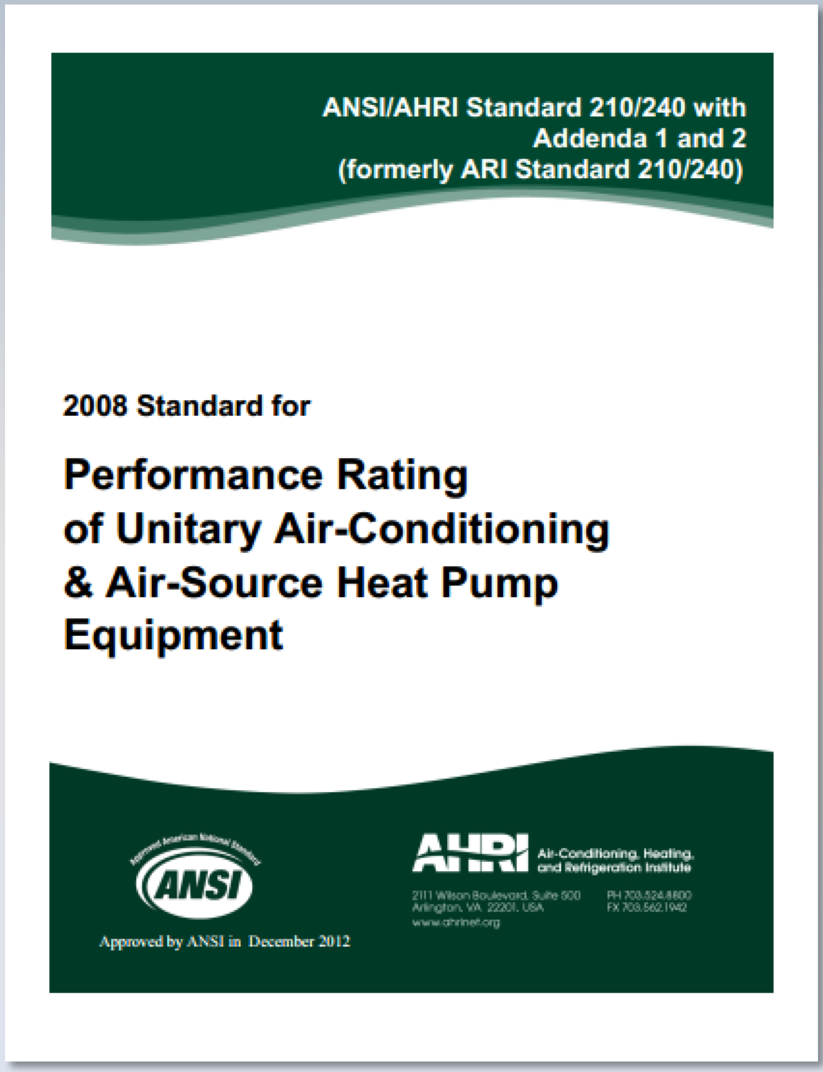
What About Lab Ratings?

- AHRI Standards govern laboratory ratings for capacity and efficiency (e.g. SEER, EER, IEER)
- Test under very specific controlled conditions
- Not representative of typical field conditions
- Useful for making an equipment purchase decision


ANSI/AHRI Standard 210/240 with Addenda 1 and 2 (formerly ARI Standard 210/240)

2008 Standard for

Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment

Approved by ANSI in December 2012

AHRI Air-Conditioning, Heating, and Refrigeration Institute

Do Lab Ratings Tell the Whole Story?

Q: Can Lab Ratings be used to predict performance in terms of comfort?

A: No, the system affects the system's ability to deliver comfort

- Small ducts restrict airflow, leading to lower system capacity
- Duct losses put heating and cooling where they're not needed

Q: How about energy use and savings?

A: No, the system affects the efficiency and run time of the equipment

- System restrictions make the fan work harder, and can cause low airflow negatively impacting efficiency and capacity
- System losses cause the system to run longer than it needs to

Q: Is this really that big of a problem?

A: Yes, yes it is… Let's take a look!

What Do We See in the Field?

- Undersized ducts due to rule-of-thumb sizing
- Upsizing equipment to alleviate a problem that was initially caused by undersized ducts

What Do We See in the Field?

- Add-ons (factory or field installed, OEM or aftermarket) that change performance
- High Efficiency filters that are more restrictive than filters used to rate performance

What Do We See in the Field?

- Bad installation choices to deal with field realities that a designer missed
- Restrictive duct fittings and transitions

What Do We See in the Field?

- Large leaks in duct takeoffs and transitions
- Missing insulation

What Do We See in the Field?

- Flex duct poorly routed and improperly supported

What Do We See in the Field?

- Failure to properly adapt existing ducts to new equipment
- Very restrictive return drop

What Do We See in the Field?

- Poor installation in response to architectural space restrictions

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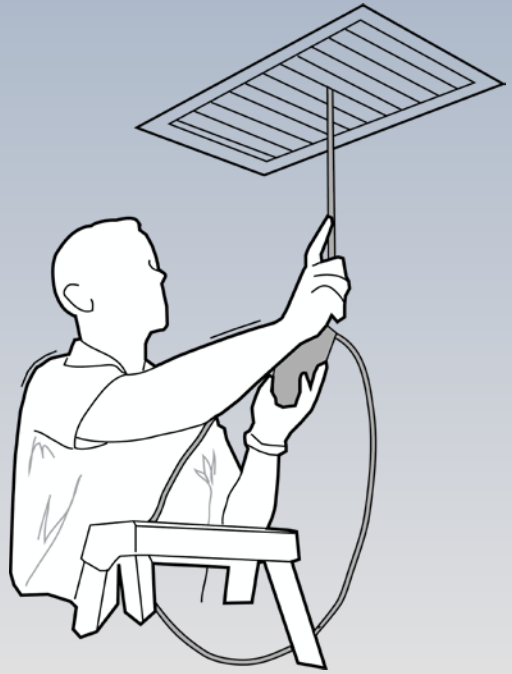
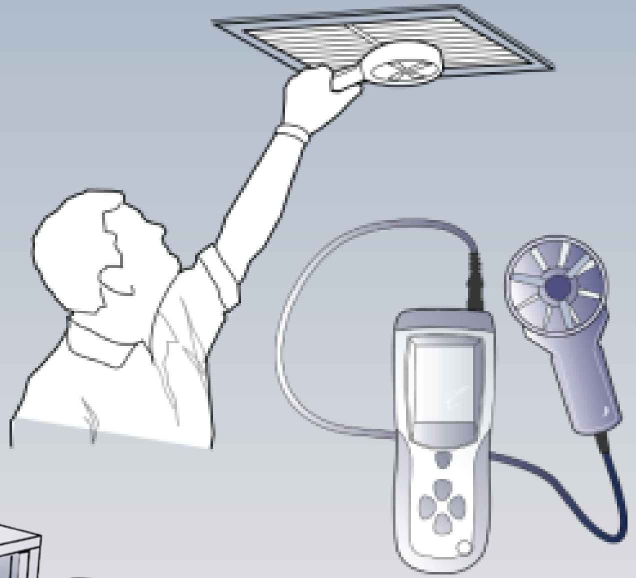
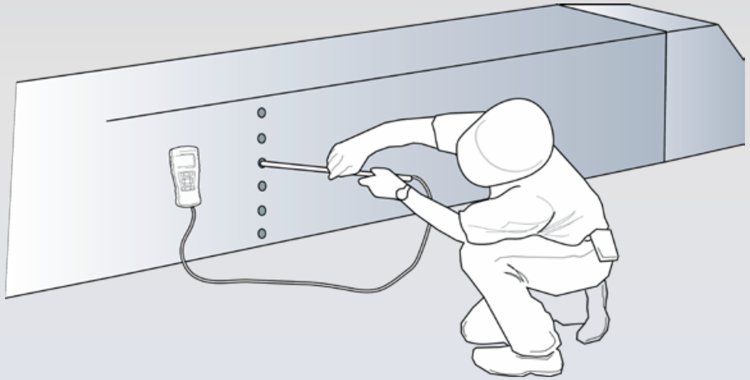
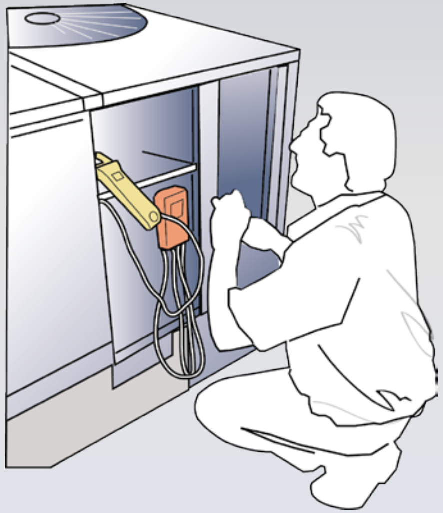
What Do We See in the Field?

- Improper duct connection methods that fail over time
- Take-offs too close to the unit and too close together on the plenum









Bringing the Issues to Light

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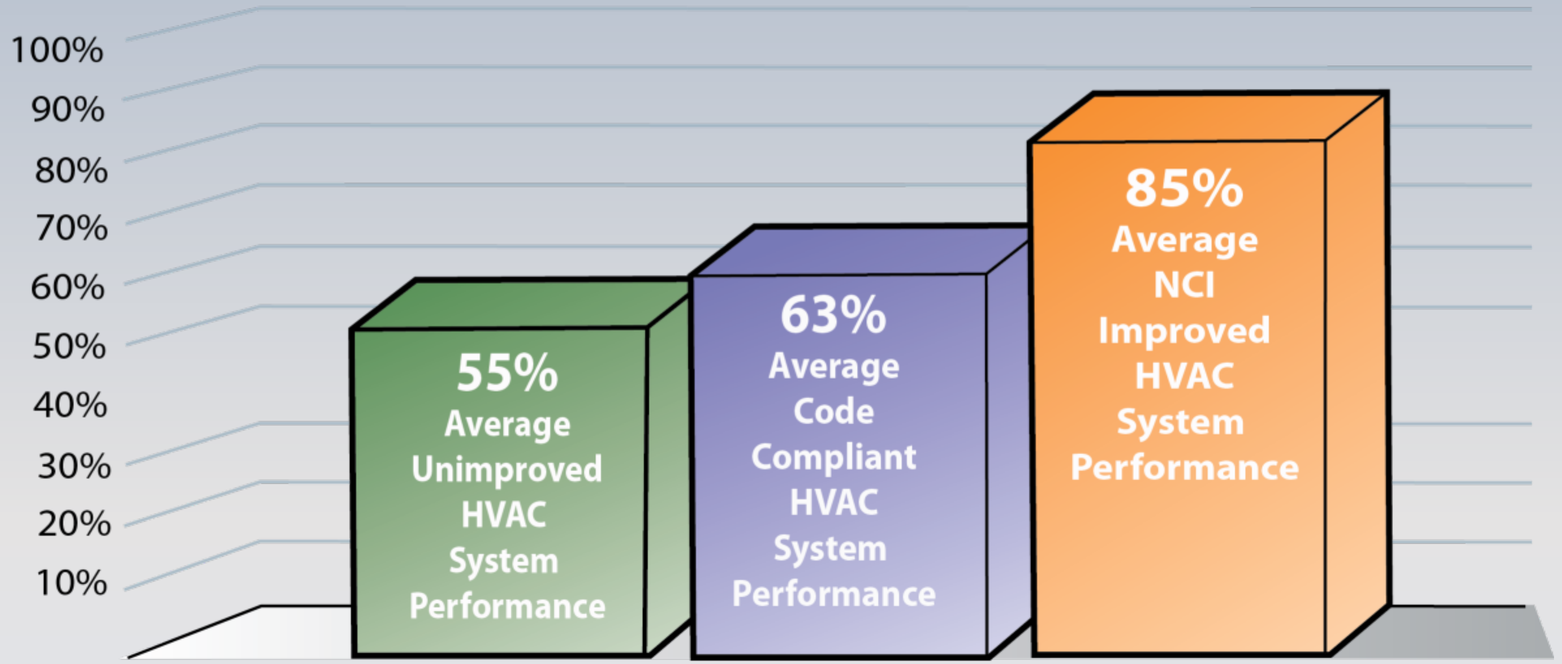
Average System Performance Scores

- Existing systems only deliver 55% of their rated capacity to the occupied space
- Energy Codes seem to help a little, but…
- By field measuring performance we can do much better!



Average Percent of Rated System Capacity Delivered to Occupied Space

Typical Existing, New Code-Compliant, and After Performance-Based Renovation

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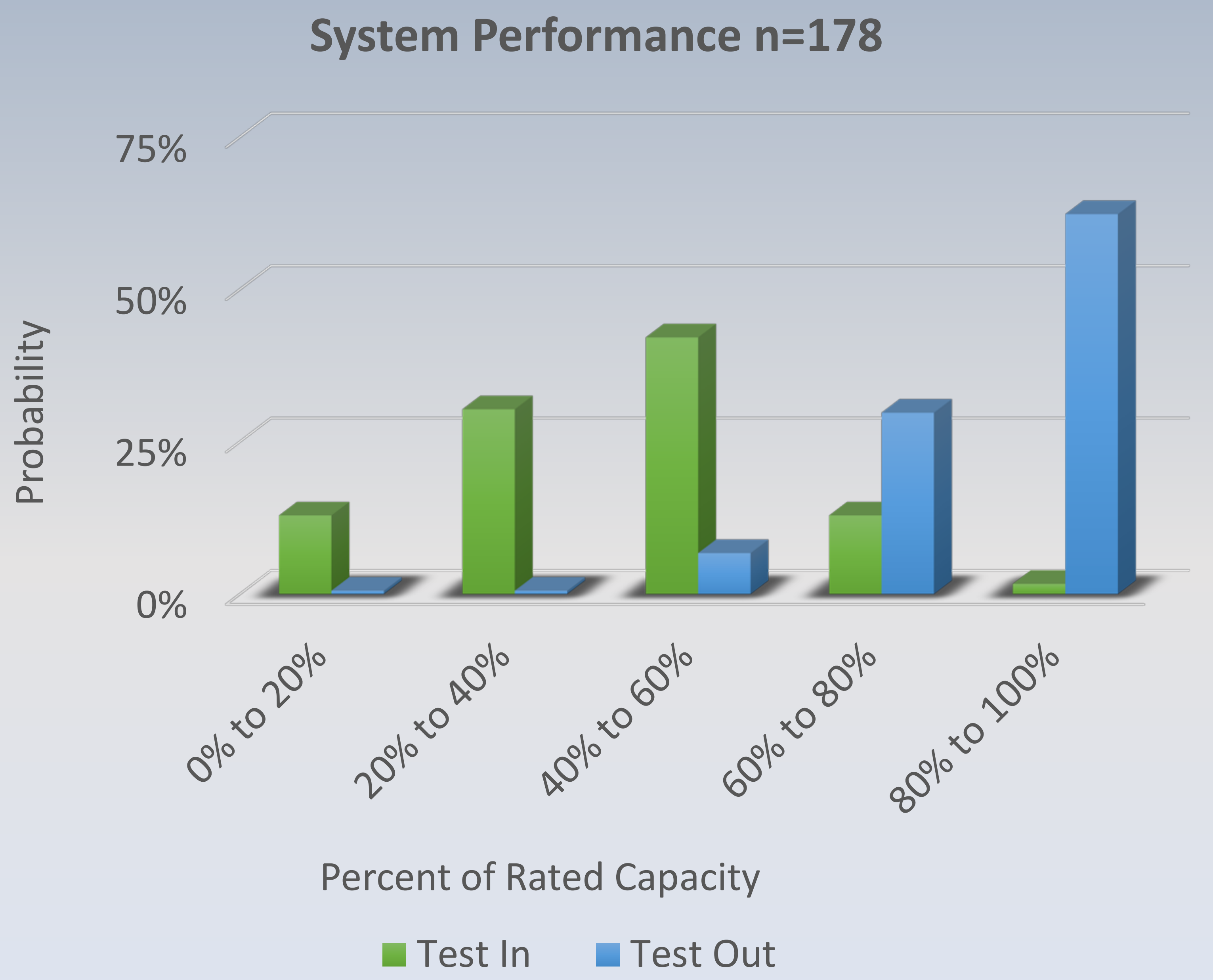
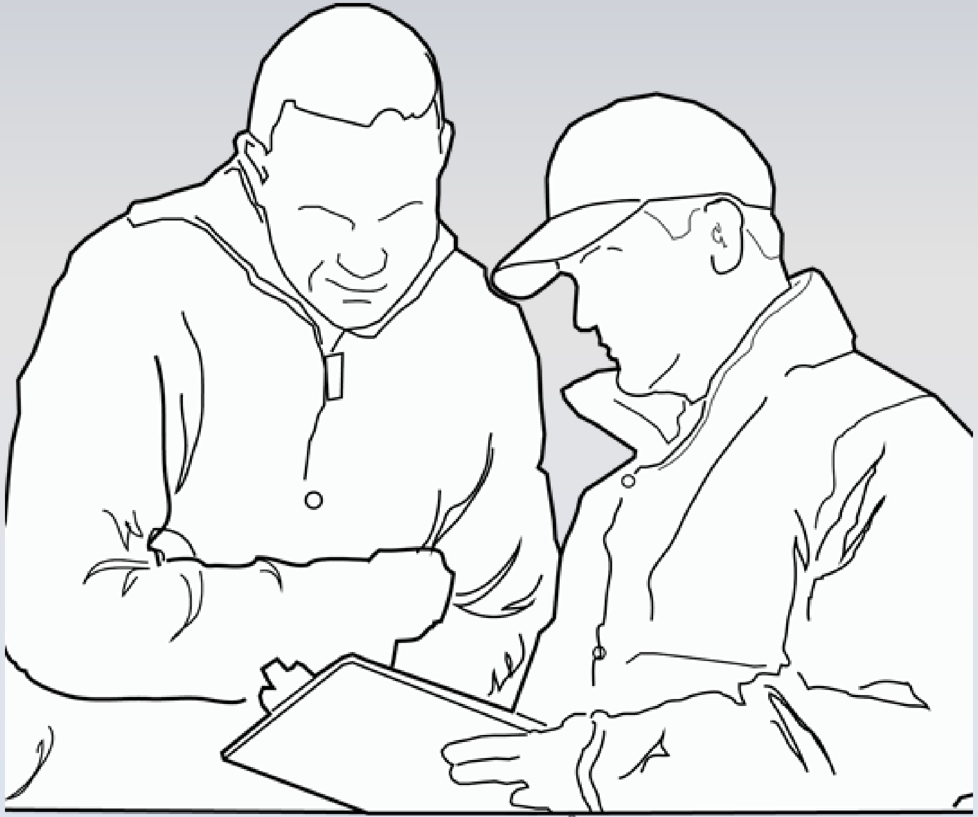
NCI System Performance Score Data

- **85%** of systems Test In at **less than 60%**
- After renovations, **75%** of systems Test Out at **better than 75%**



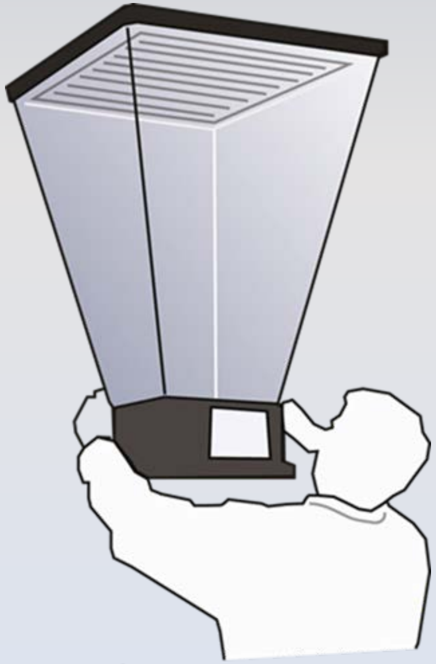
More Detail on How to Score a System

- The test procedure is for a basic 100,000 Btu output **heating** system.
- **Used by** contractors, engineers, manufacturers, commissioning agents, maintenance staff, and other professionals
- Takes less **30 to 60 minutes** to score most systems 10 tons or smaller.



Required Test Instruments

- A commercial air **balance hood**
- An **anemometer** to traverse airflow
- A series of data capture **temperature probes**



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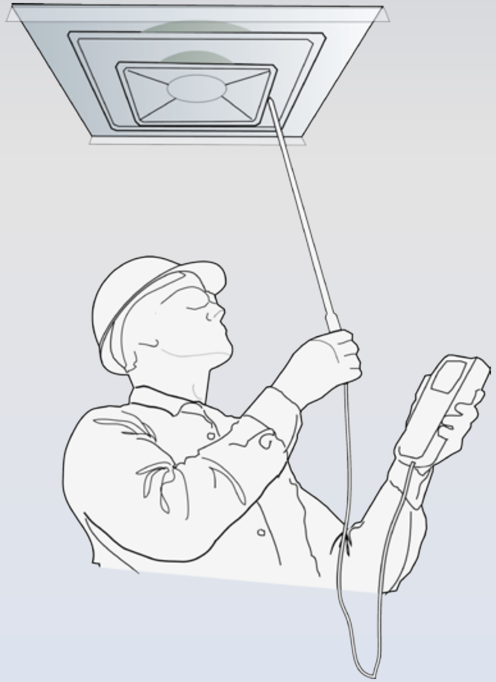

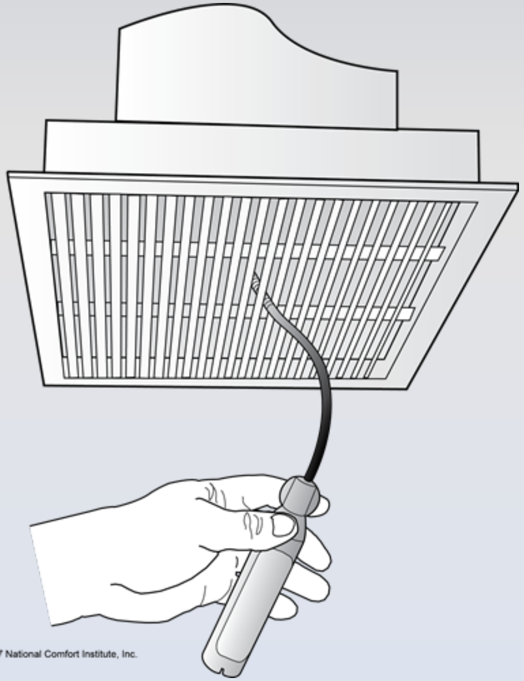

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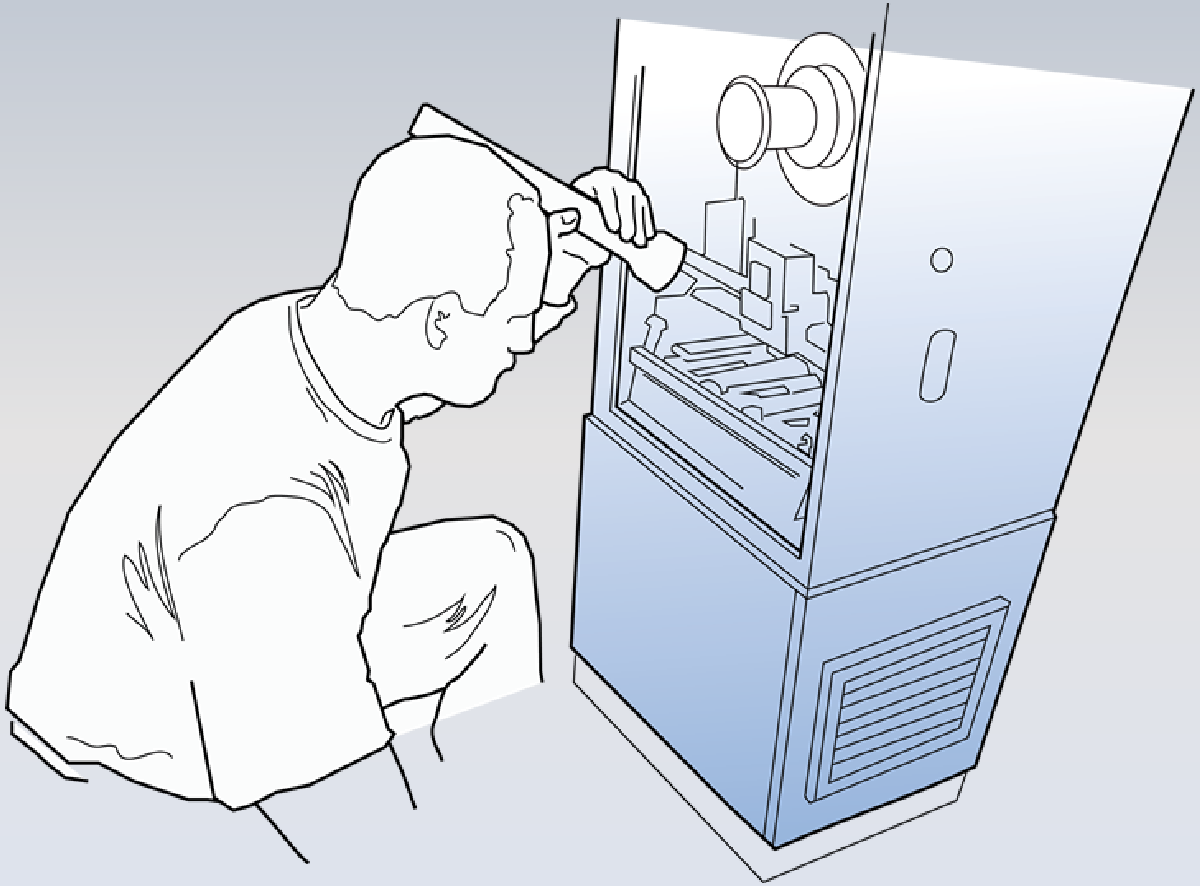
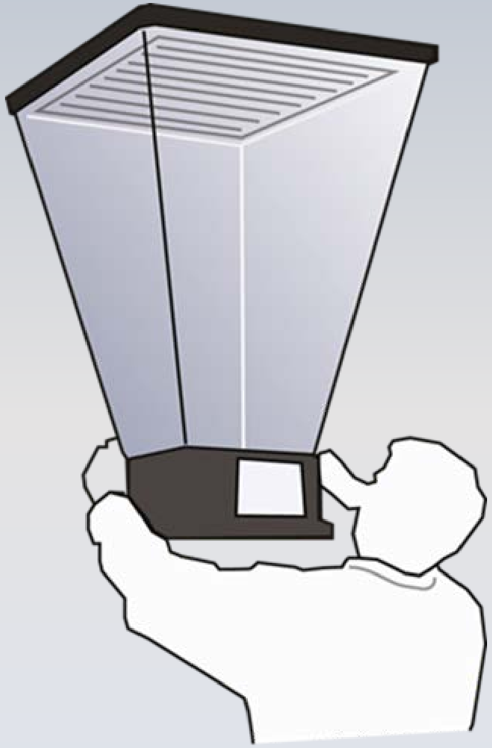
Collect Field Data and Start-up the System



- Gather equipment specifications, **nameplate data**, system design information, and measure ambient temperatures.
- **Start the system** in heating mode and allow the system to stabilize for 15 minutes.
- **Record** required information on the System Performance Score Report
- **Place temperature probes** and allow to stabilize.

Measure Airflow From Each Supply Register



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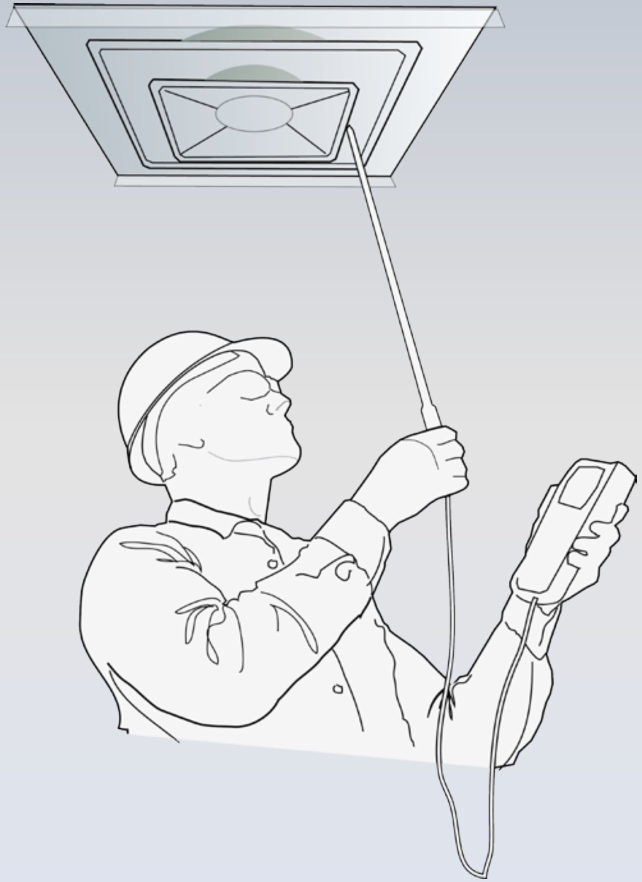
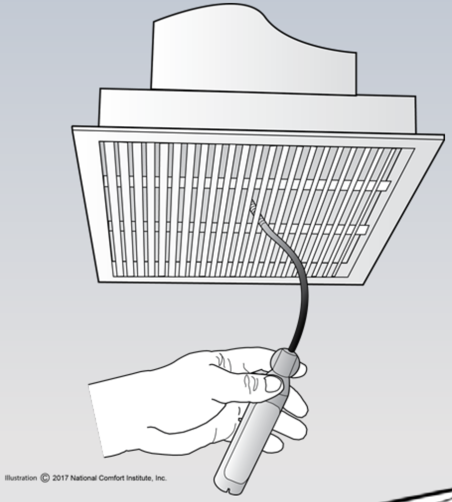
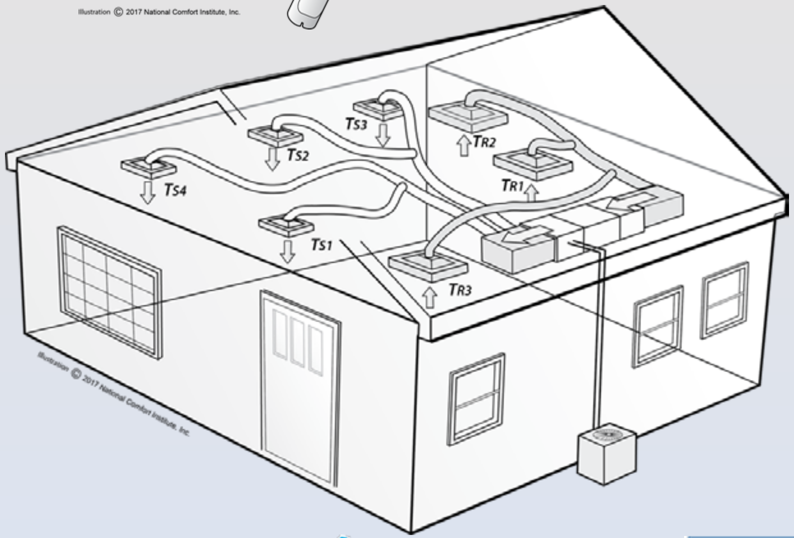
- Using a commercial air **balance hood** measure the airflow into the occupied space form each supply register.
- Where field conditions prohibit the use of a balancing hood, **traverse** the supply register to find the delivered airflow.
- Record and add together the airflow from each supply register on the System Performance Score Report. **Let's say we measured 1365 cfm.**



Find the Average Supply and Return Grille Temperatures





- **Insert probes** in 3 supply registers and 2 return grilles near the center of the system.
- The average supply air is **108.3º** and the average return grille temperatures is **72.4º**.
- Calculate the **conditioned space temperature change** by subtracting the average return grille temperature from the average supply register temperature.
- The conditioned space temperature is (108.3º – 72.4º = **35.9º**)

Calculate the System Delivered Btu/hr.

Calculate the Btu/hour the system is delivering into the occupied space using the information gathered in the previous steps.

- **Airflow** into the occupied space
- The **temperature change** between the average supply register and return grille.

Here's the heating formula:

Supply Register Airflow x System Temperature Change x 1.08 = System Delivered BTU/hr.

1365 Cfm x 35.9º F x 1.08 = 52,923 System Delivered BTU/hr.

Calculate the System Performance Score

To calculate the **System Performance Score**, we'll use the data mentioned earlier for this example system.

- The calculated system delivered Btu/hr. is **74,068.**
- The system equipment rated Btu/hr. **output** is **100,000.**

Apply the following formula:

System Delivered Btu/hr. ÷ Equipment rated Btu/hr. Output =
Heating System Performance Score

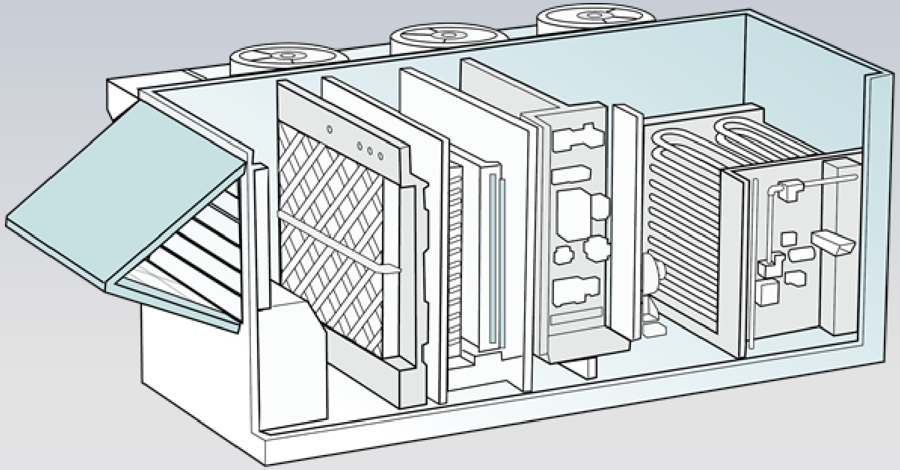
52,923 System Delivered BTU/hr. ÷ 100,000 Rated Btu/hr. =
53% Heating System Performance Score

Calculate the System Performance Loss

To discover the **percent of system performance loss**, use the information we previously calculated on the same example system.

- This system is performing at 53% of rated capacity

Here's the formula:



Rated system performance of 100% - System Performance Score of 53% = 47% System Performance Loss

Falke Recap – System Performance Score

- We walked though a basic 100,000 Btu/hr. **System Performance Score**
- Required **test instruments** were discussed
- Collect **field data**
- Measure **supply register airflow**
- Average supply and return grille airflows and **system temperature change**
- Calculate 52, 923 System Delivered Btu/hr. ÷ 100,000 Rated Btu/hr. = 53% **System Performance Score**
- Rated system performance of 100% - System Performance Score of 53% = 47% **System Performance Loss**

Test Procedure Details and Options

- Rated Capacity Under Current Conditions for a Heat Pump
- Cooling Tests
- Adjustments for High Elevation Testing (Over 1000’ above sea level)
- Systems with Outside Air Ventilation or Economizers

HEATING CAPACITIES, 3 TONS

50HCQA04											
RETURN AIR (°F db)	CFM (STANDARD AIR)		TEMPERATURE AIR ENTERING OUTDOOR COIL (°F db at 70% RH)								
			–10	0	10	17	30	40	47	50	60
55	900	Capacity		13.3	17.2	20	26	31.3	35.6	37.0	42.7
		Int. Cap		12.3	15.8	18.3	22.8	31.3	35.6	37.0	42.7
	1200	Capacity		13.8	17.8	20.8	27.0	32.8	36.9	38.3	44.1
		Int. Cap		12.7	16.3	18.9	23.6	32.8	36.9	38.3	45.1
	1500	Capacity			18.7	21.8	28.2	34.0	38.1	39.4	45.1
		Int. Cap			17.2	19.8	24.7	34.0	38.1	39.4	45.1
70	900	Capacity	7.5	11	14.9	17.8	23.6	28.5	32.7	34.2	40.4
		Int. Cap	6.9	10.2	13.7	16.2	20.7	28.5	32.7	34.2	40.4
	1200	Capacity	7.9	11.6	15.6	18.6	24.7	29.9	34.6	36.0	41.9
		Int. Cap	7.3	10.7	14.3	16.9	21.6	29.9	34.6	36.0	41.9
	1500	Capacity	8.7	12.4	16.5	19.6	25.8	31.3	35.9	37.3	43.1
		Int. Cap	8.0	11.4	15.1	17.8	22.6	31.3	35.9	37.3	43.1
80	900	Capacity	5.7	9.3	13.2	16.1	21.9	26.8	30.5	32.1	38.4
		Int. Cap	5.3	8.5	12.1	14.7	19.2	26.8	30.5	32.1	38.4
	1200	Capacity	6.1	9.8	13.9	16.9	22.9	28.1	32.3	33.9	40.3
		Int. Cap	5.6	9.0	12.7	15.4	20.1	28.1	32.3	33.9	40.3
	1500	Capacity	6.8	10.6	14.8	17.9	24.1	29.4	34.0	35.6	41.6
		Int. Cap	6.3	9.8	13.6	16.3	21.1	29.4	34.0	35.6	41.6

Testing In Cooling Mode

Procedure Differences

- Measure supply and return air enthalpy (h) instead of dry bulb temperature
- Calculate system delivered cooling capacity
- Find rated cooling capacity for test conditions – outdoor air dry bulb and coil entering wet bulb temperatures

System Delivered Cooling Capacity

$$4.5 \times CFM \times \Delta h$$

4.5 = Cooling BTU Multiplier

CFM = Total Supply Register CFM

Δh = Average Return Enthalpy – Average Supply Enthalpy

Adjustments for High Elevation (Above 1000')

- Measure cfm with the instrument set to *standard* SCFM instead of *actual* ACFM
    - Instrument will automatically correct for air density based on current barometric pressure
- Can also manually adjust for instruments that can't do it automatically

Adjustments for High Elevation (Above 1000’)

- For *combustion furnace* heating tests apply a derating factor to rated capacity to adjust for natural gas density

Example: Testing at 5000 Feet, Rated Output Capacity 100,000 Btu/h

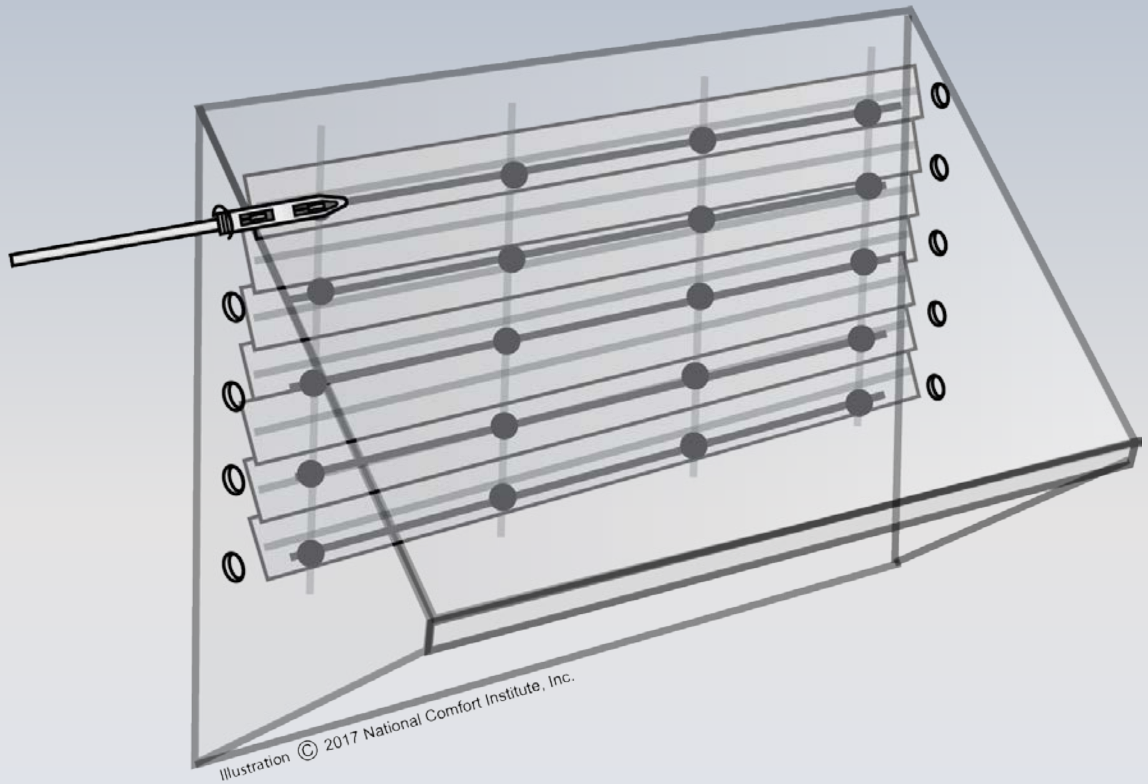
Rated Capacity Under Test Conditions:

100,000 x 0.83 = 83,000 Btu/hr

Elevation Feet Above Sea Level	Derating Factor
1000	0.96
2000	0.93
3000	0.90
4000	0.86
5000	0.83
6000	0.80
7000	0.77
8000	0.74
9000	0.71
10000	0.69

Systems With Outside Air

- Small (e.g. residential systems) block off the outside air intake
- Commercial systems with economizer set damper to minimum ventilation and perform a traverse to measure CFM
- Calculate system delivered capacity



$$1.08 \times CFM_{supply} \times (T_{return} - T_{supply}) - 1.08 \times CFM_{OA} \times (T_{OA} - T_{equipment\ return})$$

Recap - Easily Quantify HVAC System Efficiency Loss Caused by Poor Installation

- History of Performance Testing
- Test Overview
- Lab Rating Limitations
- Common Field Issues
- Typical Performance Scores
- Detailed Test Procedure Example
- Test Options and Nuances

Questions?

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